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Understanding and mitigating cascading crises in the global interconnected system

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ABSTRACT

Cascading crises and disasters in the global interconnected system are emerging topics in today's disaster risk reduction research. The primary objective is improving the capability of our societies to cope with such events and mitigate their detrimental consequences through an evolved understanding of their nature. Rather than being merely considered as an outcome of low-probability/high-impact processes, cascading events can be associated with the cross-scale accumulation of vulnerability paths constituted by events waiting to happen. In this context, instead of focusing solely on triggering events, it seems important to point out the interactions orienting the escalation of secondary emergencies through vulnerability paths.

This special issue integrates those emerging aspects with an operational approach that considers cascades as the complex, non-linear escalation of secondary emergencies. Key topics addressed by the contributions include: cross-domain modelling of interdependent systems; decision support systems; economic impact assessment of critical events; and cascades in the built environment, in social domains, and in applied emergency management. Our conclusions support the work of academia, and of public and private stakeholders, by providing a comprehensive analysis of the topic for the improvement of theory, the assessment of resilience, the formulation of policies for managing crises, and operational planning for emergencies.

1. Introduction

Cascading crises and disasters in the global interconnected system are emerging fields of research in disaster risk reduction. Adopted since the early 2000s in different contexts e.g. [11,19,3], these concepts have become more common in the global community since recent events such as the 2010 eruption of the Eyjafjallajökull Volcano and the 2011 triple disaster in Japan. Cascades have often been intended vaguely to describe some disruptive event chains or consecutive failures by associating them with the analogy of toppling dominoes or regarding them as synonymous for "knock-on" effects. However, the literature has developed significantly in the last few years, leading to evolution of the interpretation of such phenomena and to the development of specific frameworks for analysis. This research area has also been supported by national governments, international institutions, such as the European Commission, and private enterprises.

Significant new evidence has been provided on "traditional" topics related to cascading events, such as the resilience of critical infrastructure [17], and interaction with environmental hazards [9]. Moreover, the complex causal chains that join environmental dynamics to human stressors have been explored in the study of cross-border ecological crises stemming from climate change [5]. In addition, global interconnected risks have been interpreted in the light of cascading effects in major international networks [10]. Overall, the literature suggests that it is necessary to go beyond risk management in order to address the high levels of uncertainty of future challenges [18].

This special issue (SI) integrates these points of view with an operational approach that interprets cascading events in terms of the complex, non-linear escalations of secondary emergencies, as defined by Pescaroli and Alexander [24]. The main goal is to present a range of perspectives that could show the interactions and interconnections that guide the escalation of secondary events through vulnerability paths, instead of focusing only on triggering events [28]. In other words, we explore the different aspects of cascading events as cross-scale accumulations of vulnerability paths waiting to happen, rather than being merely an artefact of low probability, high-impact processes. Although this process has already started [22,30], it can benefit from the integration of more cross-disciplinary perspectives in sectors such as emergency and contingency planning [1], and scenario building [25,26]. This may include cross-domain modelling of interdependent systems [8] and economic impact assessment of critical events [13,7].

Cascading risk can be distinguished from other concepts used in the literature, such as compound, interacting and interconnected risk. This calls for a different approach to the analysis of the vulnerability drivers and its translation into operational tools for disaster management and policy making [29]. Beyond enhanced theoretical interest in cascading events, this perspective has very practical implications and opens the possibility for a number of applications that are relevant to disaster management stakeholders. In this sense, the United Nations' (UNISDR) *Guidelines on National Risk Assessment* [32] have recognised the need to include a cross-sectoral and multi-risk approach to cascades in the implementation of the Sendai Framework for Disaster Risk Reduction[1]. Moreover, [15] have acknowledged the challenges associated with the dynamics of cascading events

[1] https://www.unisdr.org/we/inform/publications/43291.

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when linked to drivers such as climate change. Finally, the concept of escalation has been applied in joint documents produced by academic scholars and local authorities for improving the training of emergency planners to cope with events such as blackouts [27].

This special issue explores the topic of cascading crises with the aim of expanding the field by means of 14 papers. First and foremost, this was made possible thanks to the interest and collaboration of many colleagues who contributed their research and committed time to the review process. Moreover, the support of the European Commission's Joint Research Centre and the University College London's Institute for Risk and Disaster Reduction was fundamental. We are confident that the work in its present form can provide a solid basis both for future literature and for the development of practical applications. To support these expectations, methodological results have been put side by side with a number of case studies that cover a broad range of disaster scenarios, which result from both natural and anthropogenic triggers. In this way, interconnections and interactions have been contextualized in the built environment and the social domains. Thus, they provide a comprehensive portrait of the topic and support the improvement of contingency planning, scenario building, vulnerability assessment and the cultivation of resilience.

2. Theory, methodologies, and organisational steps for understanding and mitigating cascading crises

This special issue has begun to address some key questions: –

- How do cascading disasters propagate and escalate?
- How do primary triggers and vulnerability paths interact?
- Which nodes concentrate most of the vulnerability and what are their carrying capacities?
- What are the relationships and interdependencies among critical infrastructure that may frequently be underestimated?
- What can be done to contain escalations, and at what spatial and temporal scales?
- How can assets and infrastructures be tested against stresses and critical events in order to promote their resilience in the face of cascading or escalating events?

In this section, we aim to provide an organized overview of the contributions proposed as part of this special issue. In particular, this SI involves three main thematic areas, which interact and converge with one another.

(a) A number of the papers assess and promote the evolution of the theory of cascading disasters, often with an emphasis on novel interdisciplinary aspects to be taken into account in future research.
(b) A group of authors tackle the development of assessment criteria for a better understanding of interdependencies. They propose additional approaches that could be of interest for stakeholders in the public and private sectors.
(c) As a whole, the issue contains a rich portfolio of new strategies that aim to improve organisational resilience by targeting emergency planning and policy making, with the support of empirical case studies.

In the rest of this section we provide a short outline of the contents of the papers that contribute to each of these themes.

2.1. Evolving the theory of cascading crises

In recent times, a number of research projects have substantially nurtured the development of the theory of cascading disasters. Notable examples include EU-funded FP7 projects such as FORTRESS[2], SNOWBALL[3], CASCEFF[4] and CiprNEt[5]. The literature cited in the introduction also suggests the need to explore additional theoretical and practical aspects of cascades.

In first instance, Miller and Pescaroli [20] apply a social-ecological approach to how psychosocial capacity building (PCB) could address the escalation of cascading disasters. Indeed, the loss of services and secondary emergencies can influence collective behaviours for which the dominant paradigm disseminated among mental health professionals would not be effective alone. The paper argues that integrating PCB will support local processes of healing, psychosocial restoration, and sustainable recovery in cascading disasters, thus mobilizing new resources for responders and citizens [20].

A different analysis is proposed by Kelman [16], who explores the possible conceptual interactions between cascading disasters and disaster diplomacy in order to understand possible theoretical synergies between these two emerging fields. Differently from cascading disasters, disaster diplomacy examines how and why disaster-related activities influence the prospects for peace or conflict. The paper suggests the idea that cascading disasters could help to map the causal pathways of disaster diplomacy while highlighting the need to make use of social perspectives from the literature [16].

The paper by Alexander [2] focuses more on merging the theoretical components of the literature with the needs of modelling and emergency planning. This is achieved by developing a magnitude scale for cascading events. This study builds upon previous findings e.g. [24,28] and develops theory from the earlier works for specific empirical uses. The magnitude scale aims to facilitate the comparison between events in order to maximize the exchange of information and the ability to learn lessons, which is the basis for improving mitigation and training, in particular in the domain of the cross-sector influences of critical infrastructure disruption [2].

The same approach has been utilised by Galbusera and Giannopoulos [6]. These authors review the role of input-output (I/O) models in the analysis and assessment of disaster impacts, in particular those associated with the quantification of multi-regional loss and responses to shocks in global supply chains. The paper highlights the emerging challenges and opportunities for I/O analysis and its application to complex disaster scenarios. The discussion approaches the contribution of new models to I/O techniques, including triggering perturbations, static and dynamic representations, and the analysis of economic resilience [6].

Finally, the contribution of our SI to the theory of cascading disasters is completed with the work of Zuccaro et al. [35]. From a theoretical point of view, their research discusses the modelling needs and the main challenges that have to be considered for the development of simulation tools for cascading effects, integrating the outcomes of the EU-FP7 SNOWBALL project (2014–2017) mentioned above. The primary goal of this paper is to derive a framework model for developing scenarios on cascading effects at varying spatial and temporal scales, using levels of detail that could be derived from what data is available at the local level [35].

2.2. Methodologies for assessing interdependencies

The analysis of interdependencies and complexities that underlie the development of cascading events is a primary aspect of interest. Accordingly, the authors of this special issue have brought a vast range of cross-disciplinary perspectives to the area of interdependency assessment.

Clark-Ginsberg et al. [4] define a conceptual structure from among the different methods used to evaluate the complexity of systems, hazards and consequences, and also their practical applications. In this research, linear and networked risk assessment methodologies are

[2] https://cordis.europa.eu/project/rcn/185488_en.html.
[3] https://cordis.europa.eu/project/rcn/185475_en.html.
[4] https://cordis.europa.eu/project/rcn/185490_en.html.
[5] https://cordis.europa.eu/project/rcn/107425_en.html.

examined in the context of multi-hazard risk assessment. This also creates the opportunity to integrate the two approaches. A three-stage process is proposed for this work [4].

Nazempour et al. [21] utilise a complex network theory framework, a perspective that has a long relationship with interdependency analysis and the mitigation of cascading effects. Taking into account relevant network metrics, their study develops an optimization-based approach for the placement of contamination detection sensors in water distribution networks. One distinctive aspect of the proposed technique is the exploitation of a complex methodology based on network theory in order to formulate the multi-objective optimization problem. The technique is also applied to a reference case study and compared to alternative methods [21].

Serre and Heinzlef [31] maintain a focus on critical infrastructure disruption, considering the increased likelihood of critical infrastructure failures associated with dynamics such as climate change, which can propagate risks in areas generally considered as lacking vulnerability. This paper develops new methods to assess and map resilience levels to floods by considering critical infrastructure networks as drivers of the propagation of cascading effects at different spatial scales. The results of this analysis suggest strategies to improve the resilience of urban environments by using decision support systems. The application is illustrated by two case studies: Hamburg, Germany, and Avignon, France [31].

A different approach is proposed by Yu and Xiang Yang [33], who explore the opportunity to capture and make use of the information content of previous crises. Case-based reasoning provides a framework for this operation. In order to describe emergency scenarios, a genetic representation based on ontology is used. To allow structured access and the retrieval of previous cases of interest, a triple-check mechanism is introduced. Ultimately, it supports the efficient and timely construction of response plans and helps to estimate the likelihood of cascading events [33].

Finally, the work of Hempel et al. [12] offers a connection with the next thematic area, as it includes an empirical case study for emergency planners. The authors address the need for an evolved concept of interdependence. By elaborating the concept of dynamic interdependencies, they take stock of current criticality assessment methods. These allow time-varying relationships and impacts to be expressed and a variety of cascading typologies to be utilised. Moreover, a software tool is introduced for representing interdependency and analysing dynamic aspects of criticality. This incorporates multiple criticality measures and its practical use is demonstrated in the case study.

2.3. Organisational resilience for effective emergency planning and policy making

The last investigation area of this SI addresses the need to understand how the application of cascade analysis and management strategies can influence organisational resilience. It uses empirical case studies to show the implications for emergency planning and policy making.

Pescaroli [25] develops an integrative research process, which aims to apply the theory of cascading disasters to the response and preparedness strategies of stakeholders in London, England. The paper investigates perception of cascading risk and proposes new quantitative and qualitative evidence to show the divergence between the awareness of risk and its management in practice. The paper discusses options for improving multi-agency coordination and organisational resilience in London. It proposes the implementation of focused training and delineates policies that could also be valid in other environments [25].

In order to assess how preparedness strategies can influence cascading events triggered in the energy, healthcare and water services sectors, Kachali et al. [14] propose a case study on interagency and inter-sectoral dependencies in Finland. The paper focuses on civil actors, such as governmental agencies and businesses. It uses semi-structured interviews and legislative comparisons. The results suggest that vulnerability in preparedness can cause the escalation of intersectoral failures. Coordinating well-targeted actions can reduce risks overall [14].

A different approach is offered by the work of Parisi et al. [23], who focus on hydrological droughts and their cascading effects upon social, economic, and environmental systems. The paper proposes Lecce (Italy) as a case study, for which the cascading paths associated with groundwater depletion and salinization of karst aquifers are described. In order to improve existing practices and increasing both local manager and end-user awareness of the cascading effects of droughts, the research uses a scenario-building process that is carried out through semi-structured interviews of water management stakeholders [23].

In conclusion, the paper by Zaidi [34] addresses the higher levels of policy making. It uses cascading analyses and systems thinking to approach the Sendai Framework indicators and disaster databases. It explores new methodologies for improving estimates of losses and damage. In order to demonstrate how a systems approach to cascading risk can improve the utility of disaster databases from reactive and static measures of economic loss to tools for assessing risk and vulnerability across temporal and spatial scales, the paper focuses on a subset of small-scale disasters and slow-onset hazards.

3. Cascading as integrative and collaborative research process: steps ahead

This special issue endeavours to gauge the level of interest in the topic of cascading disasters in both the research community and disaster management community. In order to contribute to the development a common agenda for future research, the following six strategic points are important means of improving the level of synergy between scholars and practitioners.

1. *Integrating operational thresholds and uncertainties into strategic decision making.* This aspect has very practical implications and requires the involvement of stakeholders such as critical infrastructure operators and emergency planners (e.g. airport authorities for volcanic ash clouds). Considerations to be taken into account include the variety and variability in operational conditions of physical infrastructure, but also the uncertainties in decision-making and operational management, as well as other drivers, such as climate change. There is a clear potential for large, integrated projects that could help to assess the compromises and differences between adequate levels of action and inaction.
2. *Implementing new training strategies for highly complex technological failures.* A matter of particular interest is how to promote common training strategies for coping with escalations in the technological domain caused by different triggers but enabled by common vulnerabilities. For example, key questions include the following: which improvements in business continuity strategies would help enhance operational resilience to different triggers, such as extreme space weather events and cyber attacks? How can one optimise the investment of resources by organisations and enterprises in order to cope with events distinguished by high uncertainty, high potential impact and low probability? Nowadays, the challenges associated with such questions are often discussed in different forums within the public and private sectors. Instead, future research should help integrate the response to critical infrastructure failures with emergency management, contingency planning and strategic decision making.
3. *Developing multi-hazard early warning systems and scenarios for managing highly complex events.* The integration of different hazards into common early warning systems, with the addition of societal drivers, is an essential ingredient of risk management, as well as future research. Early warning techniques should reflect the variety of expertise available in this field. Aspects to address include the

understanding and modelling of hazards (such as volcanic ash clouds and extreme space weather events), technological choices (such as decision support platforms) and information delivery (practices and policies needed for action). In tackling the complexity of cascading events, it is also important to promote common training, including simulation exercises, for triggers that could cause escalations.

4. *Integrating new tools and scenarios where hazards that interact with each other interface with vulnerabilities and societal drivers of cascades.* In this case, cross-disciplinary collaborations may aid the development of multi-layered vulnerability assessments, in which the built environment and society are jointly considered in order to stop the escalation of crises.
5. *Using cascading scenarios to assess risk perceptions and the social and behavioural needs of citizens.* Despite the fact that some of the papers of our special issue explore the stakeholder's perspective, the literature on community resilience to cascades needs to be developed further. What information is needed to improve emergency response and preparedness at the individual and household levels? When and where should it be delivered, and by what means?
6. *Comparing and understanding differences between high- and low-income countries*. One of the biggest gaps in current research is to understand whether and how cascading dynamics could spread and how they could differ between a variety of countries and socio-economic contexts. The field would benefit from more structured, evidence-based case studies, including systematic comparisons among countries, ethnographic studies and the creation of databases. In the same area, in the continuous quest for effectiveness and timeliness, the implementation of national and international relief actions calls for the development of new logistical tools and strategies.

In conclusion, the points indicated above outline some of the possible issues that could be explored in the future. The application and enhancement of knowledge on cascading disasters must be regarded as a collaborative opportunity to further disaster risk reduction and develop practical answers to the emerging challenges of societal and technological resilience. In the process of incrementing the dialogue between academic disciplines, further questions are expected to emerge. These will reflect the need to bridge the physical and social sciences, and develop new collaborations with stakeholders and end users. As Albert Einstein once wrote, *"To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science"*. The only comprehensive answer to the high complexity of cascades is to develop new synergies and understand how competencies are complementary.

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